Water Use of Coal-fired Power Plants under Carbon Constraints

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Research Motivation

- Coal-fired power plants account for nearly 50% of the U.S. electricity supply and contribute one-third of the U.S. greenhouse gas emissions.
- To deeply reduce carbon dioxide (CO_2) emissions from coal-fired power plants, amine-based carbon capture and storage (CCS) is a key technology option.
- Currently, thermoelectric power plants account for abut 40% of total freshwater withdrawals in the U.S., primarily for cooling.
- The U.S. Clean Water Act requires best available technology for most new power plants: from once-through to wet cooling towers.

Objectives

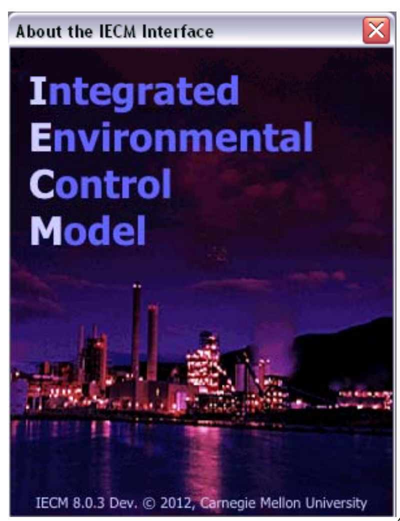
- Quantify and characterize water use of pulverized coal (PC) power plants with wet cooling towers under carbon constraints, especially in conjunction with amine-based CCS.
- Identify the effects of key factors on water use at PC power plants with CCS.

Integrated Environmental Control Model (IECM) for Power Plant Assessment

- A desktop/laptop computer model developed by CMU for DOE/NETL; free and publicly available at:

  www.iecm-online.com

- Provides systematic estimates of performance, emissions, costs and uncertainties for preliminary design of
  - PC, IGCC and NGCC plants
  - Flue/fuel gas treatment systems
  - CO_2 capture and storage options



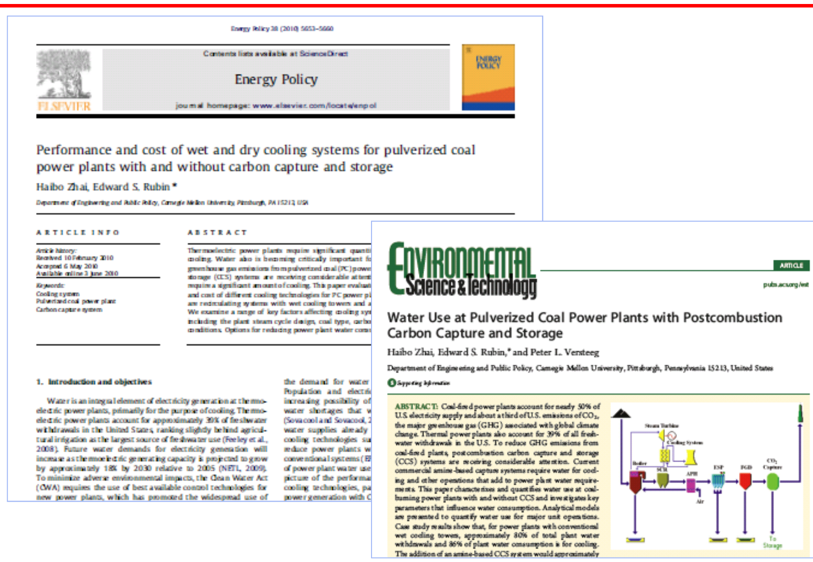
Water Systems Module in the IECM

- A water systems module in the IECM was developed based on detailed mass and energy balances for coal-fired power plants (Zhai and Rubin, 2010; Zhai et al 2011).

- The water module is able to estimate water use for:
  - making up evaporation, blowdown and drift losses in wet cooling towers;
  - making up boiler blowdown losses;
  - water use (water washing or making up evaporation losses) in environmental control systems;
  - cooling the CO_2 capture process and making up water when applicable.

- The water module includes different cooling technologies: once-through, wet towers, and air-cooled condensers for dry cooling.

Model Details Available in Publications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Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage

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Environmental Science & Technology
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Water Use at Pulverized Coal Power Plants with Postcombustion Carbon Capture and Storage

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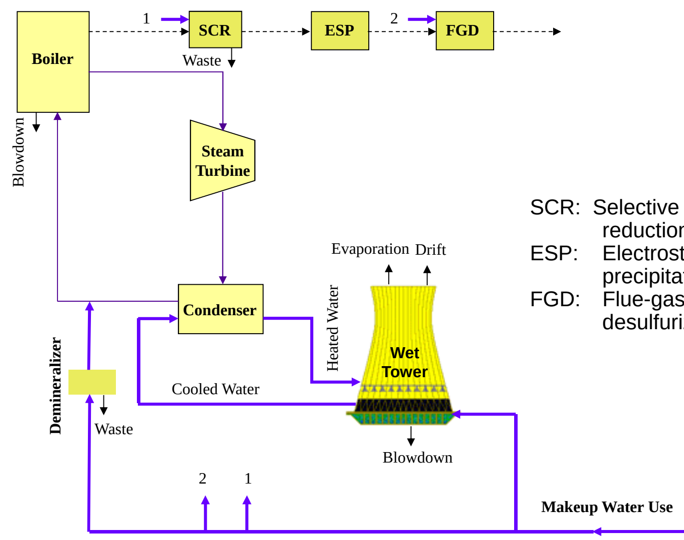
Water Configuration of A Coal-fired Power Plant without CCS



SCR: Selective catalytic reduction
ESP: Electrostatic precipitators
FGD: Flue-gas desulfurization

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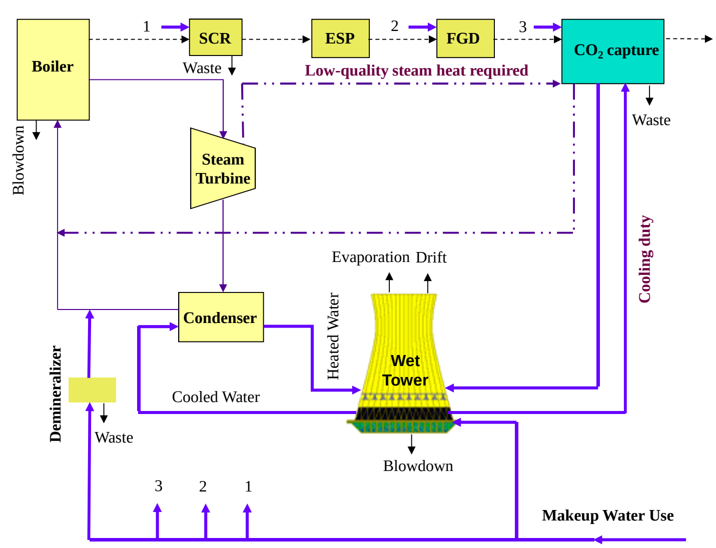
Water Configuration of A Coal-fired Power Plant with CCS



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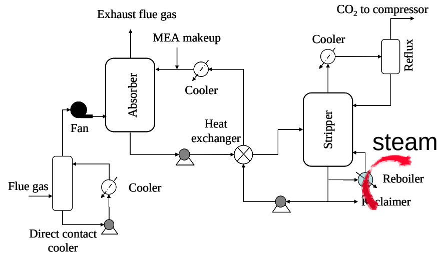
Major Performance Parameters of Amine-based CCS



Cooling water required to support
- Direct contact cooler
- Absorption process
- Stripping process
- CO_2 product compression

Parameter	Value
Capture system	Econamine FG+
CO_2 removal efficiency (%)	**90.0**
Sorbent concentration (wt, %)	30
Temperature exiting direct contact cooler (°C)	45
Makeup water for washing (% of flue gases)	0.8
Regeneration heat requirement (kJ/kg CO_2)	**3517**
Cooling duty (t H2O/t CO2)	**91.2**

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Assumptions of Key Techno-Economic Parameters for Base Plants

Technical parameters	**Value**	**Economic parameters**	**Value**
Net plant output (MW)	**550.0**	Cost year	2009
Boiler type	**Supercritical**	Fixed charge factor	0.15
Net plant efficiency (HHV)	38.4%	Capacity factor	75%
Ambient air pressure (psia)	14.7	Life time (years)	30
Ambient air temperature (°C)	15	Labor fee ($/hr)	33
Ambient relative humidity (%)	50	Water cost ($/$m^3$)	0.26
Coal type	Illinois #6	Coal cost ($/t)	46.3
Boiler blowdown rate	6.0%		
Cooling system			
Cooling technology	**Wet tower**		
water temp. drop range (°C)	11		
Cycle of concentration	4		
CO_2 removal if applicable (%)	**90**		

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Key Performance and Cost Results of Power Plants with and without CCS

Variable	Without CCS	With CCS
Gross power output (MW)	590	685
Net plant efficiency, HHV (%)	38.4	26.4
Coal flow rate (tonnes/hr)	190.7	276.6
NO_x flue gas into SCR (tonnes/hr)	0.96	1.39
SO_2 flue gas into FGD (tonnes/hr)	9.2	13.2
CO_2 captured product (tonnes/hr)	n/a	590
Cooling water requirement (tonnes/hr)	**53,530**	**100,200**
Plant water use (tonnes/hr)	**1,318**	**2,405**
Plant cost of electricity (2009 US $/MWh)	69.3	121.2

Adding CCS to a coal-fired plant for 90% would increase the plant water use by about 80%.

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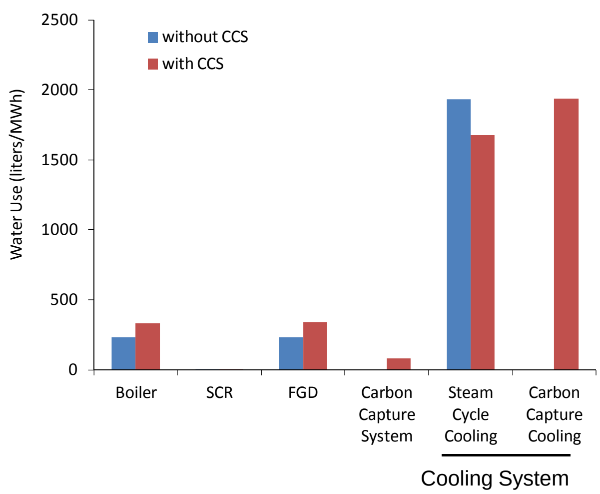
Water Use Distributions for Power Plants with and without CCS

- The cooling system is the largest source of water use (80%).



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Sensitivity Analysis for Coal-fired Power Plant with CCS

- CO_2 emission standard
- Plant type
  - Subcritical
  - Supercritical
  - Ultra-supercritical
- Cooling technology
  - Dry vs. wet systems for steam cycle cooling

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U.S. EPA Proposed CO_2 Emission Performance Standards for New Fossil Fuel Power Plants

- On Sept. 20, 2013, the U.S. Environmental Protection Agency issued a new proposal to limit CO_2 emissions from **new** fossil fuel power plants more than 25 megawatts, which would

  require that ***new*** *coal-fired power plants meet an electricity-output-based emission rate of* ***1,100*** *lb* CO_2*/MWh of electricity generated on a gross basis*.

- In the proposal, CCS is identified as the best system of emission reduction. To meet the emission standard, **partial carbon capture** via CCS is needed for new coal-fired plants.

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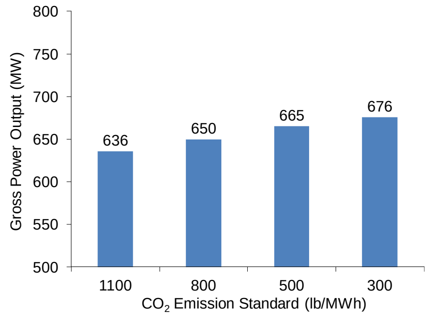
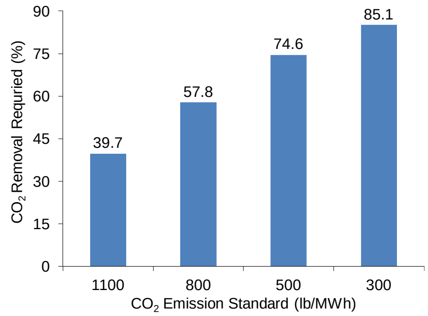
Effects of CO_2 Emission Standard on Power Plant Performance

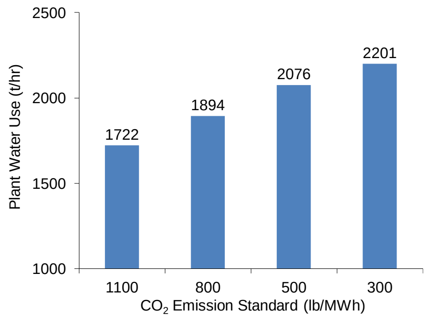
- A range of CO_2 emission limits from 1,100 to 300 lb/MWh and their water impacts are evaluated for a 550 MW-net PC plant using ver. IECM 8.0.

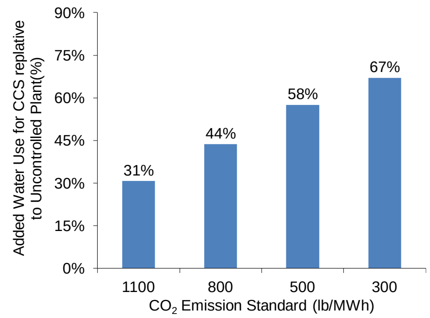




Effects of CO_2 Emission Standard on Plant Water Use

Limiting CO_2 emissions from 1100 to 300 lb/MWh would increase the plant water use by roughly 30 to 70%.

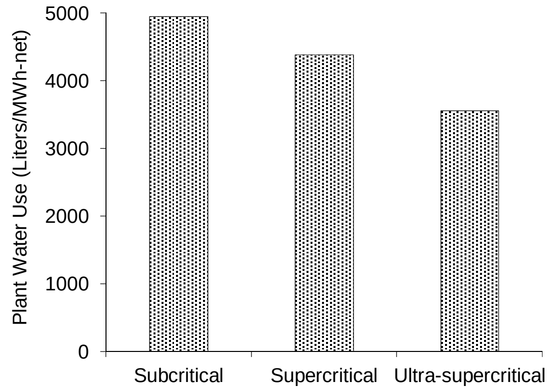




Effects of Power Type on Plant Water Use

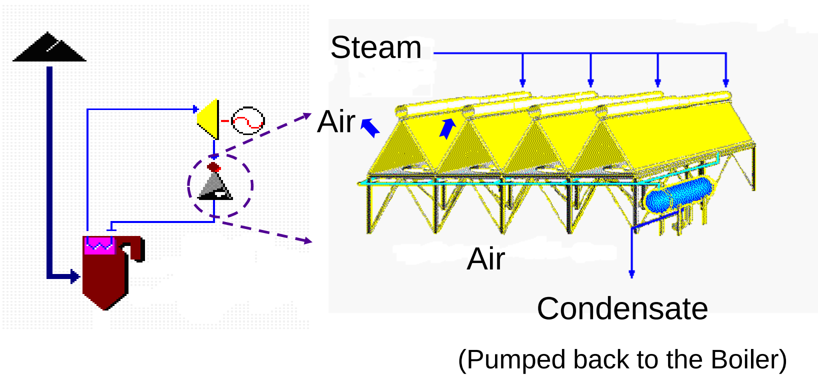
- The net plant efficiencies with CCS are 24.0%, 26.4% and 30.3% (HHV) for the subcritical, supercritical and USC plants with CCS, respectively.

Improving plant efficiency would reduce the plant water use by 28%.



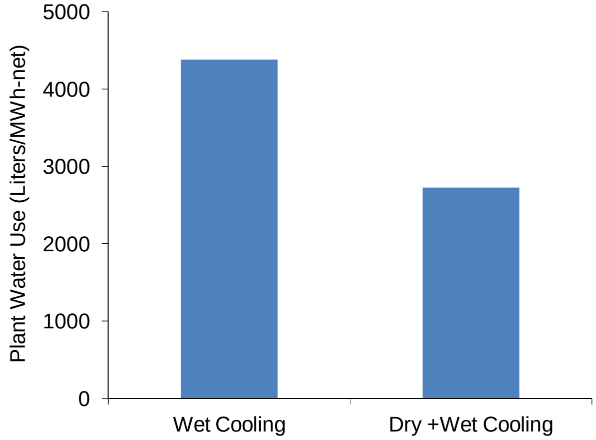
Dry Cooling: Air-cooled Condensers

- Air-cooled condensers (ACCs) utilize the sensible heating of air passed through finned-tube bundles to reject steam heat for cooling.
- There is no cooling water used in the dry cooling for the steam cycle.



Effects of Cooling Technology on Power Plant Water Use

- Wet Cooling: wet cooling tower
- Dry + Wet Cooling: ACCs are applied to cool down the steam cycle and an auxiliary wet cooling system is used for the carbon capture system.



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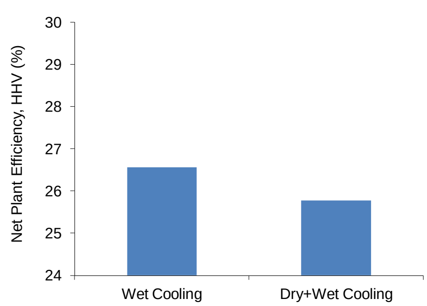
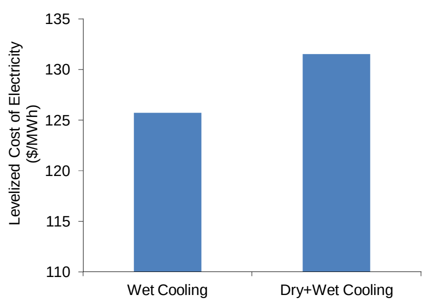
Effects of Cooling Technology on Power Plant Performance and Cost

Replacing wet cooling with dry cooling would result in about 1% reduction in net plant efficiency and $6/MWh increases in the plant LCOE.





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Conclusions

- The cooling system is the largest source of water losses at PC power plants with wet towers;
- Limiting CO_2 emissions from coal-fired power plants via CCS would significantly increase plant water use;
- Improving plant energy efficiency decreases plant water use;
- Replacing wet cooling with dry cooling would significantly reduce plant water use, but would increase the plant cost;
- There is a need for careful coordination of energy, climate change, and water resource policies to avoid a possible conflict between water supply and demand.

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Thank You

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